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Hydropower: Dimensions of social and environmental coexistence

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Abstract

Hydropower came into the energy matrix as a consequence of a sequence of technological innovations in the late 19th C. Rapidly expanding electricity demand turned hydropower in numerous countries into an "energy bridge". The rise of public awareness of environmental issues of the early 1970s put hydropower into a coexistence mode. This narrowed public acceptance of hydropower as an energy source and reduced significantly its role in the energy matrix in numerous states. In the academic literature it was downgraded as a major energy source, and the sector attended the technical aspects professionally, but the decision makers treated the dam-site and reservoir area population with woeful neglect. This aspect is addressed to restore balance to hydro-project studies. News reports about select specific cases are presented as examples to address this complex issue. Hydropower continues to serve as "energy bridge" in many parts of the world, but in most countries it can only provide a fraction of the total electricity needs. Its coexistence with other electricity sources plays a major role in environmental protection. It has to be noted that irrigation projects, urban water supply systems, flood control installations and recreational dams fail to articulate comparable disfavor noted for hydropower. Hydropower projects are notable imprints upon the landscape. Agricultural land uses are by far the most extensive of all, and these are indisputably essential. Balance in analysis should guide needed initial analysis throughout. Contemporary hydropower projects and those under construction include environmentally sensitive technical improvements to minimize the project's environmental impact.

Keywords: Hydropower; Environment; Coexistence; Electricity Demand; Additional Energy; Urbanization; The Press

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Contents

1. Introduction

> Early-twentieth-century Berlin shaped Rathenau's concept of a modern culture.- …Thinking systematically like an engineer, scientist, and financier, he believed that mechanization was bringing about a political, economic, and social revolution that was transforming the world into a global production system [1, p. 65].
>
> By characterizing creativity as having a dark satanic side, Spengler recalls the Prometheus myth. Because Prometheus stole the fire of creativity from the gods and bestowed it upon humans Zeus punished him and humans by creating and sending Pandora to Earth, where she opened a box filled with human misery and hard work [1, p. 54].

The borrowed quotes serve as stage for the analysis of hydroelectricity in an urban-global context. For life water is indispensable. Hydroelectricity is the product of water put to work. Simple language disguises a large system that resembles a spider web, in which the turbine–rotor–powerhouse occupies the place of the spider in its web. Worldwide hydroelectricity in 2000 provided 22.4% of the electricity generated by the prevalent energy sources [2, p. 376]. Numerous considerations invite political and social disfavor for hydroelectricity installations. To this the growing concern of environmental students has to be added. All of these reactions emerge in context and deserve fullest considerations. There has been a notable dearth of studies exploring and explaining why hydroelectric dams continue finding acceptance. Dam construction and its worldwide diffusion have to be attributed to the incessant growth of electricity demand to serve rising population numbers and increasing urbanization rates. Dam construction alone cannot answer this growth in electricity consumption, hence other energy sources are tapped, such as eolian, and geothermal as renewable, to cite the leading entrants since the 1950s'. Nuclear is non-renewable, but has gained acceptance in many countries.

Hydroelectric projects are conspicuous features in the landscape. Even a mini-hydro, e.g. 100 kW calls for some modification in stream flow, a weir at least; hence this barrier creates an up- and down-stream system. Large dams, 15 m and higher present a notable presence in the landscape. The actual number of hydroelectric dams expressed in absolute number varies from region to region, expressed in percent three to five would cover the world. Most dams serve irrigation, urban and livestock needs. Not to be overlooked in the US are recreational uses. The larger issue of dams is reservoir size because this determines the functional lifespan of a particular hydropower system.

Hydroelectric projects within the past four decades have attracted a constellation of articulate critics. Among these the International River Network (IRN) in the US is a particularly active entity. The World Bank has its in-house critics; newspapers report extensively on the socio-environmental tensions associated with large hydroelectric projects, and as presented the reports address the issue of the moment. Textbooks of environmental studies find hydroelectric projects detrimental. Then there are texts that avoid the topic. Professional journals such as *Hydropower and Dams* or *International Water Power and Dam Construction* increasingly include the environment as part of professional analysis. In politics this is termed enlightened self-interest. There is scarcely reference made to the water dependence and use of thermal–electric systems. Thermal plants use the water instead of the pass-through system of a hydro unit; hence much of the water is river or groundwater sourced. The absence of balance in general assessments identify agendas instead of providing scientific analysis and balance.

In the contemporary world hydropower projects by their growing size reflect the changing and rising electricity needs of increasing population concentrations. Like in other spheres of human activities, decision-makers in the hydropower sector reconcile the possible with the needed by means of the political–economic process that insures a viable environmental system. Large projects emerge out of recognition for action to meet particular societal needs and requirements. In the past religious structures of great prominence and royal palaces reflected such decisions. The industrial world and massive populations pose challenges of a magnitude previously unknown. In Hong Kong, the old airport was replaced by a much larger one built into the bay, as was done for the airports of Tokyo (Narita) and Kobe, Japan. The idea for the US interstate highway system came out of military planning, and currently the Swiss are tunneling the Alps for improved trans-Europe rail lines. Ideas, recognition of social change and corresponding needs influence decision-makers to provide what at the moment serves to meet a specific social–environmental challenge. Ideas do not turn into instant answers. A case in point is Salto Grande, the Argentine–Uruguay dam on the Uruguay River. The idea dates to 1903, its construction fell into the 1970 decade (Peron's last hurrah). Hydropower entities are for long-term service and perform in general significantly beyond expectations of critics and supporters alike (see Table 6).

2. Purpose of study

Worldwide electricity has become the dominant energy source used. Hydroelectricity serves as an energy bridge. Hydroelectric installations mirror the level of technological competence at the time of their respective construction. Focus of the analysis is upon hydroelectric systems in the environmental context and the socio-political milieu in which they are slated to serve. The dimensions of environmental and economic change tend to be

the factual variables, whereas the socio-political considerations are perceptual and cultural, qualitative in kind, hence subjective in expression and parallel the general shifts in socio-environmental moods and underlying preferences. Hydropower is considered in time context as an "energy bridge," but like so much else in human history, it too is transitory in function. The topic is presented in the context of systems analysis, as priorities and decision-making vary among the states utilizing hydropower. At this time its "energy bridge" function imparts great importance for its contribution to the world's energy matrix for multiple reasons, these are in short: (1) as domestic renewable energy resource it contributes to the domestic balance of payments; (2) it is to-date the lowest cost energy source; (3) it is environmentally next to wind energy the cleanest; (4) hydropower projects are multi-functional, and (5) the economic multiplier effect outperforms virtually all existing energy sources. Hydropower projects form an integral part of the respective economic landscape, which makes these projects part of the functional socio-spatial totality of the state. Hydropower projects serve as part of the country's energy system, which are the creatures of scientific–technical creativity in function and location (geology). Electricity dependence then provides perspective for a dam's performance and importance.

3. Hydroelectricity—the functional context

Hydroelectricity's rise to prominence can be viewed as the progeny of the scientific and the industrial revolutions. Numerous scientists over time contributed the essential steps to make the mosaic electricity into a functional energy source. It was M. Faraday who achieved the realization of a functional electric system in 1831. When he demonstrated its functionality to Prime Minister Gladstone at the time, Gladstone was not too taken, but Faraday opined, "when it produces income you will find a way to tax it." Its production evolution took another 50 years, namely the development of the turbine (waterwheel) and the rotor (generator). Hydroelectricity came on line in 1882, at the time when the industrial revolution was broadening its base and growing in energy dependence. Improvements in electricity generation and distribution systems changed industrial location options and with the dynamo altered manufacturing machinery and architecture. Electricity changed the functional operations of manufacturing installations. Engineering advances in transmission systems opened distances between electricity–hydroelectric unit-producing entity and electricity-consuming center. Transmission wires lost in diameter while electricity traversed increased distances in significantly enlarged volume.

3.1. The technical basis

The technical basis for hydroelectricity is multi-faceted; attention here is upon the physical site characteristics and the civil infrastructure. (The mechanical infrastructure is fitted into the civil infrastructure, which will be addressed in connection with project scale.) The locational options for dam siting are river grade-dependent. Geological boundary formations in many instances turn into dam sites because of optimal elevational differences, permitting maximizing potential electricity generation. Examples are Itaipu on the Paraná River and Tucuruí on the Tocantins River. In both cases it is a geologic boundary zone between a basaltic highland region or pre-Cambrian lowland plain, the Pampa in the south, and the Amazonian lowlands in the north.

In the case of Samuel dam, Jamari River, Róndonia, Brazil, it was necessary to build 8 m high dikes over 30 km in length to contain the reservoir's water, while Xingo dam on the lower Sáo Francisco River, Pernambuco, Brazil, is a very large run-of-the-river dam (currently 3000 MW, with possible expansion to 5000 MW). Hoover dam is another example illustrating how engineering design adapts to site conditions, or Denom dam in Sarawak (Malaysia) has been made into a run-of-the-river unit with a diversion tube. Engineering fosters site adaptations for the civil infrastructure. Sites are unique, but functionally the end product is uniform, a dam serving to generate electricity.

Civil infrastructure is the shell for the mechanical infrastructure, and includes the wings of the dam to control water storage, in creating the reservoir. The civil infrastructure housing the mechanical system is now generally re-enforced concrete, and for a time it was estimated that for each installed kW required 1 m^3 of concrete. In more recent years, with resort to modifications in form, concrete economies have been implemented. An impressive example of this change can be observed in the retaining wall that links the spillway and powerhouse at Itaipu. Instead of a solid cement wall, deep semi-diamond-shaped indentations allow for large volume reductions in concrete use at the same time conferring a unique identity upon the project.

The civil infracture as observed in Brazil is the product of very closely controlled cement mixtures. The project life of dams is centuries, not the originally projected 50 years. Cement on the spillway is one of the most exposed surfaces subject to robust cavitation, and within the dam attention to stalactite formation is necessary. Hence time and usage introduce structural fatigue which requires persistent surveillance. The spillway at Salto Grande, Uruguay River, was nearly washed away by cavitation. In Brazil, in recent times repairs on spillways use cement mixes including porcelain and silicates to harden the cement and minimize cavitation. It is not only building projects, but their effective maintenance proves to be a more enduring challenge.

3.2. *Hydroelectric systems and the environment*

Hydroelectric systems draw attention, analysis and a range of particular assessments, commonly particular aspects draw notice without providing a balanced analysis of the system in a holistic contexts. Among the many aspects, three of immediate concern: one—physical location and setting, two—its production function, and three—a project's service region(s). Agnostic assessment has its benefits as it exposes questionable practices and promotes improved project planning procedures among hydro project planners (examples of these appear as ''Green Power'' in the pages of *Hydropower and Dams*, also detailed in Eletrobras [3, vols. 2]). The caveats are numerous and multi-sourced. There are the environmentally aware, the socially sensitive, the politically involved and the economically cost-benefit analysis conscious that readily identify hydroelectric entities shortcomings. Select examples identify the diverse criticisms advanced, the sum of their impact should induce to create more generally acceptable hydroelectricity projects as well as achieve long-term economies within these systems.

The culture of hydroelectric project criticism is readily embraced especially by non-governmental organizations (NGO) groups and advocates of particular points of view. Dam removal was addressed in two sessions at the AAG 2001 New York annual meeting. Joseph [4] discusses the topic at length including a photo that is a lucid illustration of the ''Faustian bargain''. On page 60 Steve Brooke sits in his powerboat below the Edward

Dam (Kennebec River, Maine). While the questions are understandable, the answers to the solutions are evasive. James Kahn [5, pp. 283–4] stresses the barrier characteristics of dams for anadromous fish species. Dams are barriers, and if one has observed anadromous fish attempting to ascend rapids and sees the fatality and failure rate, the success rate for such fish to reach headwaters above Iguaçu, Brazil–Argentina, or Sete Quedas Falls, Brazil–Paraguay, without dams is zero. Fish ladders or elevators will be of use at dam sites (see Fig. 6C) [6]. What tends to be overlooked in such evaluations is the role of over fishing in the riverine system. Kahn notes the uncontrolled salmon harvest in the Pacific off the Oregon and Washington coasts, and then how many mature fish remain to make it up stream? The problem with this caveat is, what dam exists at the Georges Bank or Grand Banks where cod is scarce and haddock virtually extinct. Kahn closes the section by noting that ''… it is quite unlikely that hydropower will offer a significant opportunity to reduce the need for the use of fossil fuels'' [5, p. 284].

Dams flood land, bad and good. Bush [7, p. 403] notes correctly that reservoir formation leads to resettlement of affected population, and may result in overcrowding of existing farmlands. Huge seasonal discharge volume fluctuations become dam regulated. During the peak runoff period the spillway has to release the excess river volume to prevent dam over-topping, hence there remain heavy flood phases. The velocity of the water past the spillway frames the sediment load as well as its particle size, but the flood plain below the dam will sustain alluvial deposition changes. Reservoir size influences the siltation location and pace as well as the productive period of the project. Bush raises questions and identifies limitations for hydropower dams without addressing these conditions that are associated with irrigation dams, urban water supply, recreational impoundments, and flood control structures to cite the greatest number of dams. Curiously, the author has nothing to say about the energy use, its social value and the general environmental conservation attribute (he notes it as cleanest energy source, [7, p. 403]).

Fragmentary information is transformed into authoritative facts. Cunningham and Saigo focus on Itaipu and Tucuruí dams [8, pp. 487–8]. By the time the reservoir formed in 1984 at Itaipu, the Brazilian side was predominantly in agricultural land use, the deforestation dates to the colonization phase of the region in the 1930s, and few if any native people resided in the reservoir area by 1974–1984. Reference to the Brokopondo dam in Suriname notes, ''… Acidified water from this reservoir ruined the turbine blades, making the dam useless for power generation'' [8, p. 487]. The authors continue with their saga in Tucuruí asserting that the dam is on the Amazon River. The dam is 300 km upstream on the Tocantins, an affluent to the Para River. Furthermore, since rapids and small falls above Tucuruí make river navigation impossible, there was no navigation to impede. The water at the intake of the penstocks has protective netting, which was cleared on a continuous basis since the dam entered operation in November 1984. Since the water residence is about 47 days, or is renewed 7.75 times in 365 days, the water hyazinths in the Tucuruí reservoir have been confined to reservoir recessed indentations. The authors take liberties with the facts that collapse under scientific scrutiny and field work. There is no reference to limnology in this presentation, dependable indicator for water quality assessment. ''It is thought that 14 million Brazilians suffer form this debilitating disease'' [8, p. 488]. The disease in question is schistosomiasis. There is no reference, or tabulation for this assertion. Moreover with the population density of about 5 persons/km^2 in the Brazilian Amazon, in 2000, and most of the Amazonian population living in urban centers,

the authors provide an open window to fragile scholarship. Dams alter nature, the larger the complex, the more severe the impact (see [9]).

3.3. Electricity, water usage and the environment

Hydroelectricity is water dependent. Most thermal electricity generation is similarly dependent and a massive user of this resource. Thermal electricity depends heavily upon fossil fuels; predominantly coal, increasingly gas, and petroleum where less costly fuel sources are available. Nuclear power plants also depend upon local water supply systems, mostly river siting, but also in proximity to lakes. The data available for this water use are sparse, and rarely draw the attention in the general literature. The data exist but their gathering and organization depend upon and vary with the respective culture of the local organizers. Their general availability is associated with particular water studies.

Gleick [10] provides analysis and data. He details water uses of thermal electric plants for the US, and presents an array of data. Another important source for US data is organized at 5-year intervals by the USGS in their Estimated Use of Water [11]. For a wider perspective the UNESCO—Water for People–Water for Life [12] gives additional reference points. More general consideration for water withdrawal for thermal electricity is touched upon by Marsh and Grossa [13, pp. 256–60], as well as by Cutter and Renwick [14, pp. 81–2].

The bulk of electricity generation depends upon water availability, whether it is hydro or thermally generated. In the case of the former the quantities are very large, merely take a Tucurui 330 MW turbine that operates using 584 m^3/s, in 24 h, this comes to 50,457,600 m^3/day.[1] With 12 such turbines in place, the powerhouse passes over 605 million m^3/day, or 0.6 km^3. In this example, the water—the river—registers a water loss to evaporation, but the loss is small, possibly 120 m^3/s, since the reservoir is deep and vertical water turbulence acts as cooling system. In most thermal electricity power plants, the water is transformed into steam, hence the water is used and no longer reusable on site. Thermal power plants thus are water site dependent. The siting of thermal electric plants than depends upon a reliable water system such as rivers, local ground water sources, lakes or access to a coastal water body. Arid regions for thermal electric power plants link these to adequate groundwater basins. The question of quantities needed and re-charge time point to the complexity of the challenge to create a dependable thermal electricity generating system. Energy planners also need to address the coal and water transport question. Weight alone in most instances would influence power plant location choice in proximity to the water source. In both instances it can be said that power plant siting is very water site sensitive. In the case of hydropower it is river grade and geologic boundary zones. Thermal electric plants manifest a notable dependence upon massive ground water pools, rivers, or coastal zone locations.

[1]Some of the world's rivers have been harnessed with multiple dams, appearing like a staircase. If a turbine requires 584 m^3/s as at Tucuruí, then the computation is: $584 \times 365.25 \times 3600 \times 24 \times 23 = 423.88$ km^3/year. At Tucuri the river averages 11,200 m^3/s, or in the year the river carries 353 km^3 of water. The quantities of water needed deserve attention. Since the river rises during the rainy season, about 40,000 m^3/s there are about 2 months when it averages 2.6 km^3/day, or for 60 days a 30,000 m^3/s, that would be 155 km^3, or one third of the water needed at 100% of installed capacity. This illustrates why proportions of annual production are set at 50–57% of installed capacity. As more dams on the Tocantins are built, this percentage increases and could reach 70%. The resulting economy is significant in electricity generation.

Table 1
Thermoelectric water uses—USA (in km^3)

	Freshwater—daily	Saltwater—daily	Annual total
1990	0.48	—	177
1995	0.72	0.22	262.5
2000	0.74	0.23	269.4

Sources: [16, p. 49, 51]; [11, p. 36, 40]; [10, p. 71, 390, 392] ($1\,m^3 = 264.2$ gal, [10, p. 450]).

To convert 40 tons of coal (coal quality is here not addressed) into thermal electricity requires about 500 tons of water [10, p. 77]. Kohler [15, p. 37] provides a very different value, namely 600–1000 tons of water are required per ton of coal burned in a steam power plant. The different values recorded most likely are technology-change dependent. Gleick's data point to a 12.5 times larger weight factor for water than coal, hence the physical–locational option is weight shaped; Kohler's value make this condition significantly more lop-sided. Groundwater use causes concern for excessive withdrawal and possible surface subsidence in situ. Gleick reports about a planned thermal electric power station for Southern California, which would have lowered the local groundwater table by 15 cm per year for cooling purposes; the plant was never built [10, p. 70]. In 1990, in the US, 270 km^3 of water were used in thermal power plant cooling; Tucuruí dam alone for 12 Francis turbines requires over 200 km^3 of water per year. This provides a measurable comparison of the magnitude in water uses for electricity generation. Table 1 illustrates US thermal plants water requirements for select years. Hydroelectric systems depend upon reservoirs that sustain evaporation and seepage losses. Lake Nasser (Aswan High Dam) has an "overhead river" that moves about 440 m^3/s, or 14–15 km^3 of water losses annually. Benefits exact certain costs, in this case it is water loss. The concept of water prizing advances as socio-economic systems turn increasingly water dependent and cost management sensitive.[2]

UNESCO [12, p. 230] records that the high income countries use more than half of the freshwater withdrawn in thermal electricity generation. Thermal power plants require large amounts of water for cooling of the generating system. This water demand is highest in the most developed world regions with the highest population densities [12, p. 263]. In the Eastern US and Central Europe the water withdrawals range from 10 to 1500 mm/year compared with China where this range is 1–10 mm/year [12, p. 263]. Water withdrawal and use vary greatly among states. Irrigation uses in the late 1980s exceed 66% of all fresh water withdrawn in Japan; in West Germany nearly 68% of water used served thermal electricity [10, p. 329]. The competition for water uses calls for prudent evaluations to minimize flawed projections and subsequent critical water and electricity shortfalls.

Different observers bring varied judgments in assessing dam impacts. The evaluations are in good part descriptive-background influenced. All of these observations deserve most careful considerations. As Meadows [17] wisely noted it is incumbent upon "all" to recognize that there are limits to resource depletion. Hence, the focus has to be conservation and sustainable environmental management. This theme was given added weight in Our common future [18], in which emphasis addressed furthering greater equality

[2] By the mid-1950s professionals in the US Department of Agriculture emphasized the urgent need for a concerted effort of water conservation in the US (see [15, pp. 35–46]).

in resource use and conservation. What would further a better presentation of consensus lies in systems analysis. Hydropower systems, small or large, make their imprint upon the landscape in proportion to their size. By choosing this energy source sovereign states answer to their national economic needs and social–political interests. In the environment, the fluvial regime sustains a significant transformation, so does the fauna and the flora including the flood plain. Changes of this magnitude ideally are decided by plebiscite. While experts and political decision-makers are credited with honorable intentions, the public mind that decides on such large issues has to include in its considerations that these projects will serve five or more generations. To judge the extant projects, and there are select failures, the services rendered by hydropower systems globally compares very positively.

3.4. Installed hydroelectricity systems—the world—1950 and 2000

Installed hydroelectric systems increasingly share with other electricity generating systems variable ratios in an individual country's energy mixes. This is partly attributable to the limitations of individual states fluvial systems and their hydroelectric potential. Then there are the time and financial consideration that respond to immediate electricity needs. In the last 30 years, notably where large population displacements in future reservoir areas occurred, local opposition to large projects acted as a retardant vector to dam construction. Flawed policies and insensitivity to the local populations adversely affected by large projects point to planning short-sightedness. Inadequate environmental assessments compounded the rising opposition to hydro projects. This in spite of the growing negative environmental impact of fossil fuel powered thermal electric installations and the rising energy costs—both for coal as well as for petroleum and gas. Each energy sector responds to specific market forces, hence when one sector has significant price shifts there will be generally a spillover effect into all other energy sectors. Here the construction and diffusion of nuclear thermal plants can be cited, as these come with their specific problem baggage at very high costs and which are very complex to manage. Despite multiple reservations and political evasiveness, the hydroelectric "bridge" continues to expand.

Hydroelectricity contributes 20% of the world's electricity generation (Table 2) consumption. This number fluctuates with the availability of reservoir water stocks. Some states are nearly 100% hydroelectricity dependent, such as Paraguay and Norway. Other states have virtually no installed hydroelectric systems, such as Kuwait, Saudi Arabia, or Libya. Water for people [12] provides a global view and perspective for the continued use of this energy source:

> A major benefit is that the continuing development of hydroelectric potential will reduce emissions of green house gases and other air contaminates from thermal power plants. Each additional terawatt of hydropower per hour that replaces coal generated electricity offsets 1 million tons a year of carbon dioxide equivalent. One third of the total carbon dioxide global emission of 22.7 billion tons in 1995 (WRI et al., 1998) was produced by the energy sector through the combustion of coal, oil and gas. Many of the countries producing a large percentage of their electricity with coal have underdeveloped hydropower potential. Hydropower in a mixed system enables the more efficient use of less flexible technologies and reduces not only

Table 2
Hydropower: installed, percent change, potential—1950, 2000

	1950 installed (MW)	2000 installed (MW)	% change 1950, 2000	% hydro 2000	Potential, 2000 (MW)	% built 2000
Africa	485	22,122	4461	22	158,400	14
Asia	7584	190,953	2418	19	1,606,000	12
Europe	27,355	241,317	782	23	1,450,000	17
North America	53,569	178,957	234	18	1,290,900	14
Oceania	944	13,281	1307	24	120,000	11
South America	2164	109,370	4954	67	866,900	13
World	92,105	756,000	721	22.4	5,492,000	14

The potential data record the inventoried potential to 1993. These values shift with additional inventory research and possible change in definitions and economic valuations [20].

> greenhouse gases but also particulate pollution, which causes respiratory disease, and compounds causing acid rain, thus neutralizing agricultural lands and forests [12, pp. 254–5].

While the authors of the above assessment identify the environmental hazards, and identify hydropower among the environmentally cleanest energy sources, it is at most an "energy bridge", not a solution to the world's energy needs. The authors identify their more specific concern when they note that hydropower potential that remains unused in coal burning states spells significant increases in carbon dioxide emissions on an annual basis with all the well-known consequences. Humanity has to harness its technological talents to create an energy source that provides a smooth transition to a non-pollutant, inexhaustible and low cost energy source. Electricity systems have to be powered by this novel energy source. The transition has to be completed in several decades, phasing out what the world electricity systems depend upon presently, in 2006–2007.

The maps (Figs. 1 and 2) serve to demonstrate the change in the hydropower sector 1950–2000. The Table 2 affords an appreciation of the quantitative shifts over time globally.

The maps focus upon the pace of change in the hydropower sector. As urbanization rates gain in magnitude and momentum, the annual rates of electricity generation–consumption turn into a driving force to enlarge the electricity-generating infrastructure. Local policy makers turn to least cost and most proximate available electricity sources. Proven hydropower technology is local in origin, least costly, and in a nation's domain.

The Figs. 1 and 2 provide a global perspective on the significant change in total installed electricity systems. Infrastructure expansion is worldwide, but the changes are regionally impressively varied in magnitude and composition. In 1950, hydropower had a pronounced presence except in Africa. The demand by 1999 had reached such levels, that hydropower could not keep pace with the growth in electricity consumption. The shift in dependence upon thermal electricity points to the need to plan for an early and effective energy transition. The 1990 and 2001 electricity production graphics (Figs. 3 and 4) illustrate the pressure upon the sector for increased output [2, p. 510, 19, p. 482] and

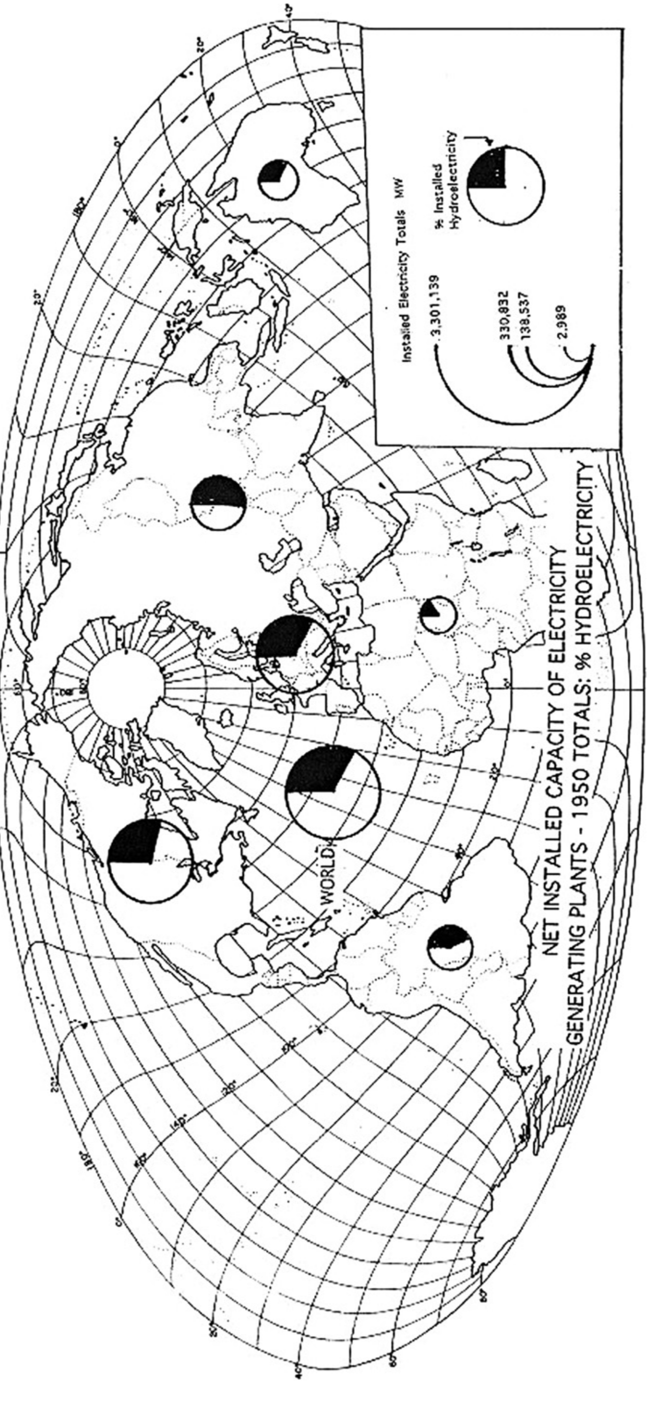

NET INSTALLED CAPACITY OF ELECTRICITY
GENERATING PLANTS - 1950 TOTALS: % HYDROELECTRICITY
WORLD
Installed Electricity Totals MW
3,301,139
330,832
138,537
2,989
% Installed
Hydroelectricity

Fig. 1.

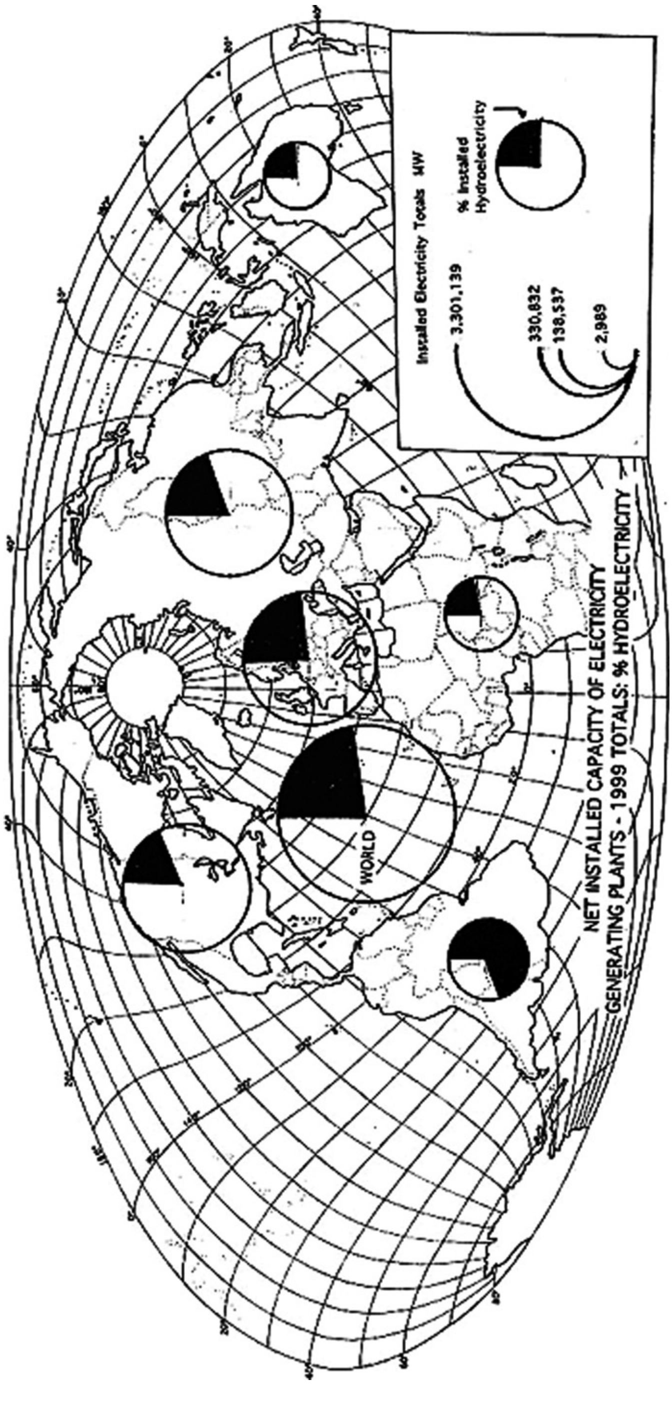

Installed Electricity Totals MW
3,301,139
330,832
138,537
2,989
% Installed Hydroelectricity
WORLD
NET INSTALLED CAPACITY OF ELECTRICITY
GENERATING PLANTS - 1999 TOTALS: % HYDROELECTRICITY

Fig. 2.

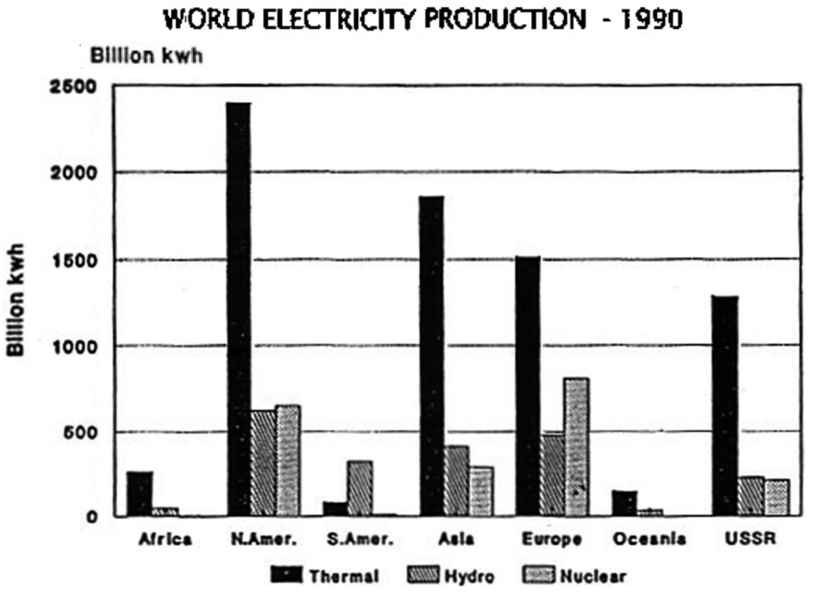


Fig. 3. The UN data are shown for several regions in 1990. North America proved to be the most dominant electricity user then. Thermal power proved to be the dominant sector. U.N. (1992), Energy statistics, yearbook—1990, p. 482 [21].

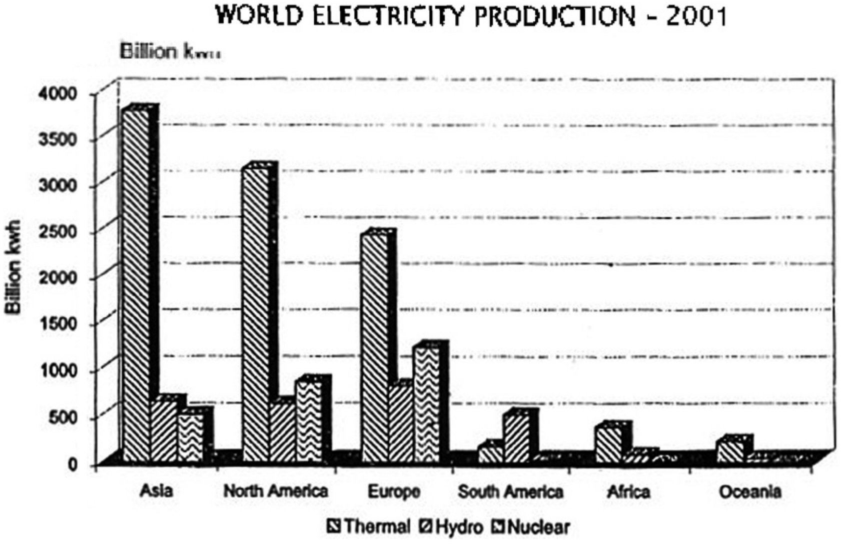


Fig. 4. The 2000 data illustrates notable changes in electricity production globally. Russian data became part of the European data sphere, hence this growth. Asia turned into the dominant world region of electricity generation, U.N. (2004), Energy statistics, yearbook—2001, p. 510 [2].

illustrates the regional shifts in volume within one decade. Regional changes in hydropower are captured in Table 2, but the totals point to the pressures upon infrastructure expansion to respond and meet the burgeoning demand.

3.5. Many points of view

World Rivers Review is the publication of the IRN. From the perspective of pristine river thinkers and geomorphologists this publication fosters a river's natural integrity. The IRN is similarly concerned about the populations that reside in potential reservoir areas for hydroelectric projects. As an NGO organization this is an advocacy group. Hydroelectricity projects are uniformly unacceptable to it. While it is inviting to dismiss their position, their point of view, it is necessary to listen and to consider how to integrate criticisms and build hydroelectric projects that are functionally more productive and socially more responsive to local social contexts. WRR is generally strident in perspective and tone. As an NGO the group offers no alternative to national energy needs or how to assist in providing for energy uses of changing societies. Criticisms of irrigation dams are rarely raised and then in muted tones. IRN supports and attempts to protect the financially poor riverine populations in potential dam–reservoir areas. It avoids the demographic issues and sidesteps the larger economic issues that form part of social systems in general. The environmental challenge is significantly larger than IRN recognizes. The rising demand for electricity is such that a 7.5% increase in annual electricity demand is such, that as the pressure for larger electricity systems expands, the effectiveness of IRN is notably vitiated. IRN may have an audience in the US, in a world of multi-cultural agnosticism IRN's advocacy position is awkward and readily perceived as foreign intervention in local policy-making and local political systems while the rest of the world lacks the capital resources needed for what the group advocates.

Silenced Rivers (1996) [22] is an example that captures and inventories in detail the hydropower shortcomings. McCully is oblivious to the infrastructure needs and economic constraints of an urbanizing world. Hydropower is a local energy resource, which serves as a thermal electricity substitute and/or replacement. Not unimportant is that it contributes to the domestic balance of payment for the fossil fuels that did not have to be imported and did not pollute the environment. Water use in hydroelectric systems is a through-put with minimal water loss. Thermal electric, fossil fuel powered, are water users, and most of this water is turned into steam. In 2000, 515 million m^3 of fresh water were used per day by the US utilities [11, p. 36], withdrawn from rivers and groundwater. A larger perspective would further sounder analysis. McCully focuses on dam construction costs (Silenced Rivers, 1996, p. 140–1) without including in his assessment the multiple uses to which electricity is put, its economic multiplier effect, as well as its general dependability. McCully has a point of view that contributes to considering the topic and illustrates the fragility of the agenda approach. To-date hydropower continues to be the lowest cost electricity source [23, p. 556 and 559, 24, p. 14].

Hydropower dam removal has appeals to environmental analysts and students of water resources, such as P. Gleick, especially in the Biennials *The World's Water*. In the 1998–1999 [26] volume report is on the changing status of large dams, Chapter 3. Dam removal is considered in detail in the 2002–2003 Biennial Report [25] and most of the activity is US based (The AAG 2001 sessions have been cited). The World Commission on Dams report graces the 2002–2003 year Biennial Report, and K. Kao-Cushing provides a general summary. Then there are the news media, restricted here to the newspapers, mostly *The New York Times* and *The Wall Street Journal*. Reports in the press tend to be sporadic and generally address a particular condition that adversely affects generally a group of

people. Such reporting possibly contributes to promote the needed attention to achieve more balanced solutions in the project region. Curiously missing from the newspapers is the long-term impact of large dams and their economic contribution to the local and state economies. Emphasis is upon hydroelectric power projects, treating the bulk of dams with benign attention. The real issue, conservation, fails to draw the necessary attention as it generates very limited traction. That is the segment where gains would most effectively benefit environment and society.

The press covers the topic globally illustrating perception and reaction of local interests. These news reports record the more attention fetching concerns articulated by the roster of local interest groups opposing dam construction, for reasons of population displacement, favoring dam removal, and species protection. Rationalizations declaring hydropower dams detrimental to local interests have to be accepted and used to understand these presentations within an environmental, social, and economic context. A list of news report titles serves to illustrate the range and variety of local perceptions and sentiments. Emphasis is upon the general rather than the particular resources for project implantation, modifications or removals.

A large sample of titles provides a synopsis of what is deemed news worthy by the press about hydro projects:

1. "Argument in Maine will remove dams for salmon's sake" [27].
2. "Chinese project pits environmentalists against development plans" [28].
3. "Battle of what may be the West's last big dam" [29].
4. "Dam building threatens China's grand canyon" [30].
5. "Ravaged by famine, Ethiopia finally gets help from the Nile" [31].
6. "Para Sempre" [32].
7. "Island Unter" [33].
8. "Between an oasis and an artwork of history" [34].
9. "Chinese groups seek to halt a dam and spare a treasured place" [35].
10. "Government rejects removal of dams to protect salmon [36].
11. "Traditional spirits block $500 million dam plan in Uganda" [37].
12. "Dams aren't forever" [38].
13. "The Colorado from River to Lake" [39].
14. "In life on the Mekong, China's dams dominate" [40].
15. "A vast Brazilian project for water diversion…" [41].
16. "Cracks show early in China's big dam project" [42].
17. "Unloved, but not unbuilt" [43].

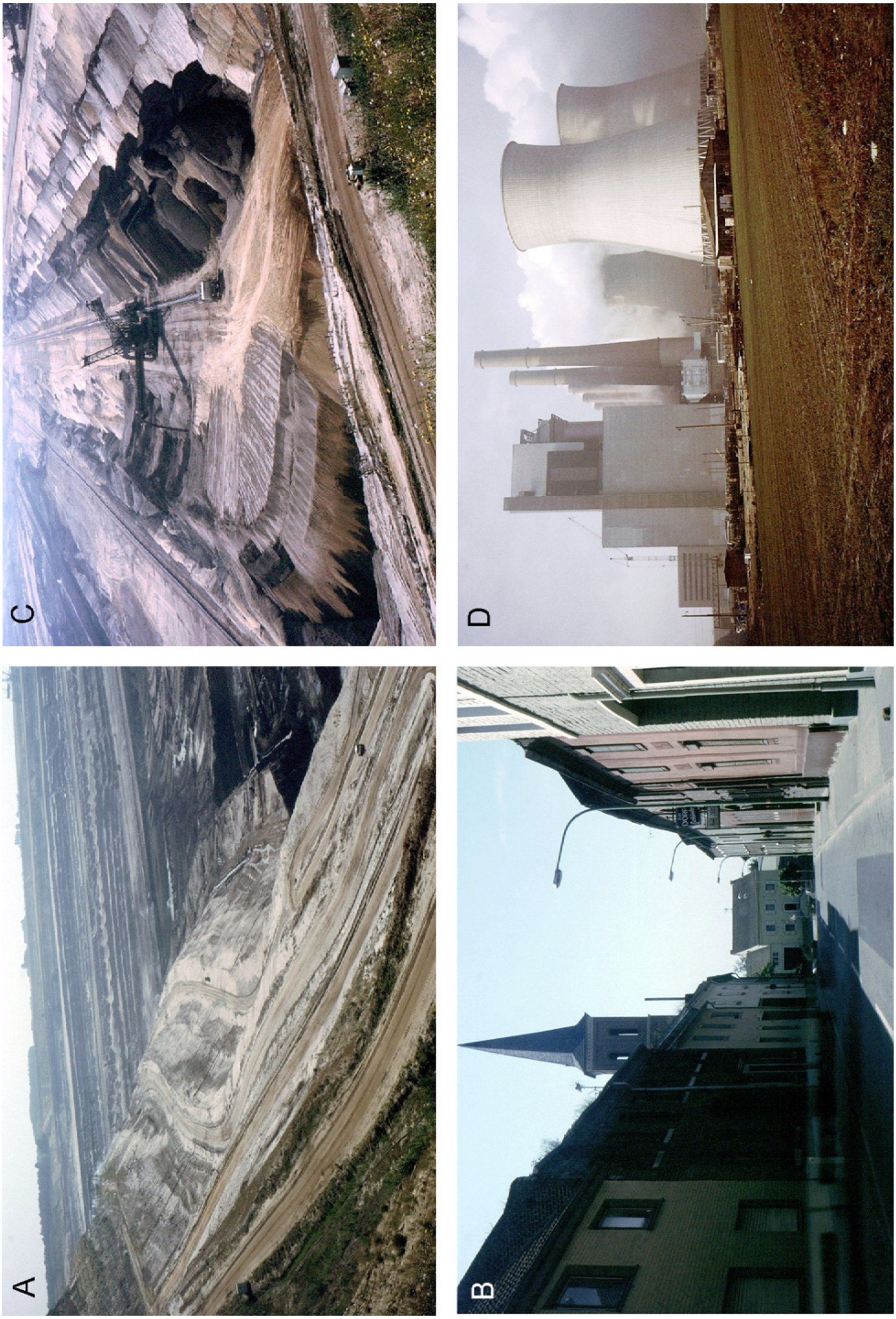
An examination of each item would point to a constricted and short-term project role. As most dams serve 100–200 years, the immediate objections are understandable, for the long term they hardly matter and in most likelihood will be contradicted by actuality within a decade or less. "Island Unter" addresses the dam, but the real issue is that a rustic youth hostel will be lost in the future reservoir area. A clash of economic interest, the local vs. the global. "Between an oasis and an artwork of history" [34], Hasankeyf dam reveals the clash of historic certainty vs. the future's unpredictability. While sympathy sides with respect for history, impending electricity demand mobilizes the instruments of change. Humanity imposes spatial reorganization while ignoring environmental conditions.

A proposed reservoir on the Animas River illustrates how interests perceive projects and consider the same in a proprietary context. "Battle of what may be the West's last big dam" [29] informs how interest groups manipulate hidden agendas. It is industrial–urban water, which would provide the water to turn coal into slurry for pipeline transport. Thirty years ago the dam would have been built as a run-of-the-river project; however by 1997 it was pork for one and an endangered river for another interest group. Times and priorities change swiftly and in unexpected ways. In China energy needs and environmental worries foster project reassessment as presented in "Dam building threatens China's grand canyon" [30]. The NU River Projects will be built to deliver electricity and water to the increasing number of urbanites in the region. Areas once remote from the more populated region of a country have lost their status of isolation. Tyler provides a fine summary of conditions for the initial construction phase of the three Gorges Dam, its magnitudes and including social dislocations [42]. Included in this report are the international ramifications, such as the US Export Import Bank was discouraged from providing support for the project. In the social sphere local people expressed their experienced hardships in terms of imposed relocation, gross underpayment of compensation, and suspected "massive corruption." Opposition to dams in China at this time is a throw back to sky-writing. Other states can be expected to emulate this practice (notably in South and East Asia). All of the objection to and concern about hydropower dams illustrate the diversity of perspectives and the singularity of electricity demand (see [43]). The spatial requirements of a functioning project and its service time are not part of local concern. Identified priorities tend to be past based and have to be incorporated into the education of all the people serviced by hydroelectric projects. In a way it is a clash of urban dependence and rural-isolated people who are inferior in political clout. There are far fewer conflicts surrounding dams for irrigation than hydropower units as residents in proximity to these projects have prospects of access to and deriving benefits from their creation. In space and time dams leave large footprints, different audiences read these in the context of their needs, interests and perceptions.

3.6. *Hydroelectricity in spatial perspective*

Hydroelectric projects are limited in productive site options. River basins and associated flood plains have served humans as preferred settlement belts at least since the inception of the agricultural revolution. Invention of the waterwheel, and by extension the turbine, changed river systems from water sources and transport routes into a readily accessible energy source. Competition for this resource awakened interest that staked out changed spheres of economic productions. Rivers, their dammed waters, could be transformed into a salable commodity, electricity. Change in hydro projects and transmission systems

Fig. 5. (A) A lateral view of lignite mining at Inden, west of Cologne. Coal from this mine powers a nearby thermal–electric power plant feeding into the regional power grid system. (B) An evacuated small town just prior to its demolition to remove the overburden to gain ready access to lignite deposits in place. The residents had been relocated to planned communities on restored mined-land. (C) Open pit lignite mine coal is placed on a conveyer system that feeds into nearby thermal power plant. Magnitude of operation and energy dependence provide visual context for environmental change. (D) The cooling towers and the powerhouse provide the visual scale for the regional electricity demand. This 1998 photo illustrates the urban-industrial encroachment upon the local farming system. At the time of the photo, the complex was surrounded by active farmland uses.


A
B
C
D

created a spatial order that responded to growing urban electricity needs and industrialization's requirements.

Hydropower project sites vary in size and so do the essential reservoirs. Site choices are subject to numerous considerations; foremost are physical/geological, cultural, political, economic, and environmental variables. In general, large projects tend to be placed distant from densely populated regions (only possible since transmissions systems became long distance in the 1940s). Cultural sites are generally avoided (the Aswan High dam and several dams in Turkey may alter this limitation). In different parts of the world the political perceptions change with local needs. China is electricity starved; it will seek to harness a large percent of its economically available water power. Germany has too little land and its rivers are too small for numerous productive hydro projects. For the moment Germany turns to exploitation of its brown coal reserves and to extract these deposits the earth is peeled like an onion. In brown coal districts villages and small towns are razed to provide access to the coal seams (Fig. 5). Open pit mining here in a way is like reservoir formation behind dams. Governments implement policies that address the national need and interest. While hydroelectric projects occupy large tracts in km^2, consider an oil refinery and its tank farm. How much space do these occupy and their respective locations? Is their environmental impact adequately considered? The B.P. refinery in East Texas occupies 1200 acres ($4.86\,km^2$) without tank farm. What are its environmental and social hazards? [44]

Hydropower projects have multiple economic attributes that countries consider on their respective merits. Use of local water power reduces the pressures on balance of payments, notably when electricity has to be imported (Canada sells hydroelectricity to the US, France sells nuclear-generated electricity to Germany). Thermal energy depends mostly upon coal, gas or petroleum, and much of this has to be imported. Thermal electricity's water dependence is scarcely noted, and the US in 2000 used over $525 \times 10^6\,m^3$/day, or over $\frac{1}{2}\,km^3$. Transport costs and generating losses raise electricity costs and burden domestic industries with increased electricity tariffs. Twenty years ago the Austrians objected to a dam on the Danube. The government explained that the thermal plant would produce pollution and put the issue to a plebiscite. The hydro project got 70% of the popular vote. Needs and options narrow access to dependable electricity supplies and depreciate the alternatives.

Dams for electricity generation can be virtually absent if the demand for energy is modest. Project size and site selection are a reflection of site and market. The environment does not stipulate project size or site. To ignore the environmental impact carries its capital costs and social price tags. Bulbular turbines can be installed without a civil dam infrastructure, but to date their productivity is limited. The environmental burden of dams is their up-stream and down-stream impact. The optimal dam is the run-of-the-river unit, as there is no reservoir; an example is Xingo, 3000 MW on the São Francisco, Brazil, or a minimal reservoir, behind Pangue Dam, Bio Bio River, Chile, 540 ha, and 450 MW (or 833 kW/ha), which equals nearly \$90,000/ha/year. Evaporation rates, stagnant lateral reservoir arms, plant infestation, water lilies, downstream river scour, these have to be considered. Nothing has been said about agriculture and the role it has in sediment loads of river channel changes. That the topic is of notable concern and is global in scale is best presented with reference to the 2002 Iguaçu (Iguassu) Symposium. In most instances the hydropower projects draw lower siltation rates than other dams because of size differences. It is a serious problem which receives the necessary attention [45, vols. 2]. But then there

are possible ways to resolve local problems. At Balbina, which should not have been built, Quiroga, the project chief at the time, found a way to keep the turtles' breeding ground below the dam. The INPA biologist disputed his idea; he went ahead and ordered numerous front loaders to build a 3 ha sandbank below the spillway. Within a year the Uatama River turtles used this sandbank as their breeding ground. Itaipu (Fig. 6C) has installed a "natural" access for the Paraná dorado to make it possible for the fish to return to its spawning waters upstream. Remediation is possible, it needs to be identified, and then be carried out. Dam siting is geological–climatologically based. Electricity demand is such that in the spatial perspective policy makers and engineers have to identify optimal sites with minimal environmental and social dislocation. In some ways the environmental variable can prove as difficult to manage as the human. An example is the "Paraná-Medio" project. Slightly to the north of Santa Fe-city, Argentina, in 20 years or so energy policy makers will revisit this 1700 MW project. Once on paper, delayed yes, forgotten, no (see Section 9 below). Similarly, Argentina and Brazil are resuming reviews for Garabi Dam on the Uruguay River. Large projects are planned for low population density areas. Urban poles make for large footprints in the hydroelectric landscapes to minimize electricity costs.

4. The political dimension

Hydroelectric projects are in the political sphere for reasons of size, costs and public service. Interests, competition, envy, corruption, and disinformation serve particular interests rather than promote the general welfare. Political interests tend to be short term to advance select agendas. Hydroelectric projects provide electricity for generations while one time opponents joined history and are resting in oblivion. Attention to politics is essential as it readily crosses local, national and often international boundaries of spheres of influence and interests.

Electricity production is like the water supply system, it is in the public domain. Wittfogel (1957) [46] identified the hydraulic society, and this has its history. In the twentieth century, electricity enlarged this dimension to embrace the "electrical society." From private origins to public systems electricity spawned a complex network of government involvement (see in particular T. Hughes [47]). Price systematization, safety rules, environmental regulations, risk management, local norms, and service standards for the sector emerged with time. In US, the Federal Power Commission (F.P.C.) emerged. Policies for electricity provision and regulation became part of federal government oversight. Then the government entered the dam building activity in the 1930s, first, Boulder now Hoover Dam, followed by TVA and the large projects on the Colombia River (TVA turned into a price gauge for electricity rates in the 1930s). Then symbols of national resolve and enhancement of the standard of life, more recently this energy source (starting in the 1970s) has been identified as environmentally and socially insensitive and undesirable. A form of "bi-polarity" has found considerable acceptance in the popular realm as the above cited newspaper reports illustrate. Popular sentiments, predominantly well intentioned and poorly informed, influence anti-hydroelectric perceptions especially well illustrated in the report of World Commission on Dams [48].[3]

[3]By 1996, the World Bank prepared an assessment of its role of financing large hydro-projects (see [43]).

Fig. 6. (A) At Sete Quedas (Seven Falls) the annual average for the Paraná is 9070 m^3/s which is forced into a narrow, deeply incised streambed cut into basalt. At this location, the channel is nearly straight. Guaira to Itaipu is about 170 km, and the grade difference is 120 m. The resulting reservoir is 1380 km^2 and contains 29 km^3 of water (photo dates to July 1982). (B) In 1982, the powerhouse positioned in the main channel was approaching its crest. The visible openings in the upper structures serve to position the penstocks, which transfer 700 m^3 of water per second to the turbine. The inset photo affords a scale perspective of project size. This photo dates to 1986, when the diversion channel power block was completed. By 2005, there were 20 turbines on line, with the last two installed in the 2000–2005 period. (C) By 2000 the Itaipu managers had created the needed infrastructure shown to facilitate the upstream movement of anadromous species in the Paraná River. The photo provides a composite view of the installed fish ladder and water controls [6, p. 29]. (D) 1993 frontal downriver view of completed powerhouse with 18 turbines, 12,600 MW, then. By 2006, two more units were installed, or 14,000 MW are available for electricity generation. The six-story building in the upper portion of the photo is the operational center. The white feet are the individual penstocks. Buildings in lower right foreground and upper right serve as assembly and repair facilities above the generating units.

The World Commission on Dams is the creation of the 1997 Large Dams group workshop sponsored by the World Bank and IUCN (The World Conservation Union [49]) convened in Gland, Switzerland (11–12 April 1997). Of the 39 invited participants, 38 in

attendance laid the foundations for the WCD study. Summary of the 1997 Gland meeting identified the positions that were rife with claims but unsupported with substantive quantitative data [50]. A.K. Biswas provides an assessment of the WCD report [51]. Biswas is chief of the World Center for Water Management, Mexico. Biswas questions the selection of the Gland 38 and their unilateral decision of what to evaluate and what criteria to use. Biswas characterizes the WCD's claims as "highly exaggerated" [51, p. 96].[4]

> Biswas notes: ..."The World Bank, after initially making positive comments on the WCD process, now seems to have very little interest in changing its policies to reflect the recommendations of the WCD report" [51, p. 97].

Biswas brings the needed perspective to assess the WCD report and in that spirit he notes:

1. The WCD assumed a mandate without authority. Twenty-six individuals took it upon themselves to start a commission.
2. The process used was opaque, secretive and autocratic.
3. Who authorized the 38 persons to create an international commission and confer an international mandate upon it?
4. Since there were NGO's in support of the indigenous who would be displaced by the projects, but there was no representation for the farmers who might benefit from irrigation systems dam related. Potential beneficiaries of dam projects were excluded from presenting their views. [51, p. 97]

> Biswas notes with concern: "The current emotional debate on dams is somewhat akin to a solution-in-search-of-a-problem approach, where the a priori solution becomes 'dams or no dams', depending on the lobby concerned. Such process is scientifically unacceptable, socially disruptive and environmentally dangerous [51, p. 97].
>
> Those affected by dams and have "to pay the cost of their implementation are made their direct beneficiaries..." He quotes G.B. Shaw "Some men see the world as it is and never ask why; I dream of things that never were and ask why not" [51, p. 98].

In the interest for the general welfare anywhere, virtually all hydroelectric projects are subject to government regulations. These are large projects, occupying often large public tracts, their influence radiates over large areas, possibly large regions of super-size states

[4] Professor Khagram's analysis [52] is based on his service with the World Commission on Dams (WCD) as senior advisor for policy and institutional analysis 1998–2000, and its final report preparation writing. There must be a significant pool of data, but this study is rather enigmatic in its data use. Not even the graphics provide a clear idea. Fig. 1 identifies undersupply of performance—here power, irrigation, water and other services are lumped into one. This puts into question which is the derelict sector. Fig. 2, Capital Costs Performance reflects the political–economic environment rather than the technical, a rather unreliable measure to assess project effectiveness. It is surprising that a WCD staff researcher neglected to include solid data identifying the range of underperformance of large dams. Cost overruns for operation and maintenance are cited but without the specifics when these data exist. Dam construction continues and reflects their out performance of all other energy sources available to date (see [23, p. 559, 561]). One has to ask why Norway, Switzerland, Brazil and China are so hydropower dependent? Countries identify specific energy needs and apply particular energy policies that meet those needs and conserve the environment.

such as Russia, Canada, China, the US and Brazil, to name select examples. In a comparable context, irrigation projects escape the adversarial status attached to hydro. It serves to illustrate how selected publicity influences public opinion. As stated elsewhere, hydroelectric projects alter river regimes in numerous ways. Irrigation dams cause comparable changes, and irrigation agriculture uses 70% of the available fresh water supply world-wide, reaching in numerous cases 85% of the captured water. In the Indus Valley irrigation, water withdrawals have led Indian Ocean waters to move upstream to salinize the lower Indus River floodplains. This is also the case for China's Yellow River. Furthermore, many of these irrigation projects turn into malaria and schistosomiasis host areas. Is it advisable to stop irrigation for food production to feed the populations in dry land regions? This is a serious dilemma, as the water is needed to service societies. What is essential is to improve the levels of information in all sectors. It is the political arena where balance in public education has to originate. In politics, officials tend to be short-term guided; hence the remedies have to originate in the professional–technical sectors, rather then expect balanced solutions out of the political milieu.

In the hydroelectric realm the politics of resettlement calls for attention. This is a sensitive topic politically, most difficult socially, and costly economically. If a state opts to build a large hydroelectric project in the context of economic development, part of the project costs must include adequate-plus compensation for those who are forced to relocate. This increases project costs, but in the name of development the resettled have first call to be put on the road to self-development. This student has observed this process at Itaipu, Itaparica and Tucuruí, is familiar with the conditions at Yacyreta, Salto Grande. So far the resettled fared best, hardly great, at Tucuruí and Itaparica. And this is generally the issue most prominently employed to consider projects negatively [53]. A similar consideration applies to the brown coal fields in Germany.

In 1988, Brazil introduced royalty payments to the county (municipio) in which the hydroelectric project is located. The motivation is to provide compensation to the electricity producing region and financial support from the electricity-receiving region. In the case of large projects this creates a tax base that is generally unknown in interior Brazil. The effect of this can be observed in Breu Branco, a town created by Eletronorte and now center for a silicon smelter. Its mayor has used the tax revenues to visibly great advantage for the community (last visited in August 2003). Breu Branco is favela—(slum)-free, an impressive accomplishment. A similar process is at work in Parapuebas, beneficiary of the Carajas iron ore royalties. Politics can be positive, even if modest in scale, to improve the lot of those left out of the larger schemes in the national economy and the accruing benefits.

5. Social and environmental interests

Hydroelectric projects are drawn indirectly into the spatial reorganization of the social order and the growing urban systems. This process is too large to be comprehensively planned and creates its own system once the project enters electricity generation. Electricity availability turns into a centripetal force fostering spatial reorganization of particular regional economic geographies. This spatial reordering in population distributions is partly a consequence of the project reshaping established population clusters, and competition for the amount of space absorbed by the complex. Changed social needs are being acted out in an environmental setting in which established spatial order relationships are subject

to a shifting spatial order in the land use hierarchy. Many of those who are forced to relocate seek to resettle in the immediate project region. Possibly more significant in the long-term perspective are the urbanites that may turn into suburbanites, and as significant if not more so are the one time rural populations who migrate, following the centripetal pull of the urban center, and become urbanites.

Population shifts associated with hydroelectric projects tend to focus upon those who have to relocate. Their status has been considered above, and they must be equitably resettled. Population migration that follows the transmission lines to the larger cities turn into energy users and indirect hydroelectric project supporters. The resulting ecological footprints create an anomalous condition, which was in general not inherent in hydro project plans. It is social change that alters the way society uses space and responds in its way by turning the environment into a metamorphing system serving a limited number of one-time floodplain residents.

Many of the environmental modifications root in human actions, hence hydropower projects are imprinted upon the physical landscapes as part of the infrastructure formation that complex societies implant in the physical landscapes. Project magnitude and its environmental mark identify the technological level of its builders and users. In a way D. Whittlesey's [54] concept of "sequent occupance" can be invoked to suggest how technological change modifies resource base, land uses and occupance. Modifications and/or obliteration of historic landscapes present difficult choices. There is the respect for the past, and then there are the needs of contemporary society. Oktem's [55] study identifies this condition at length, set in Eastern Turkey.

In one case archaeological–historic sites disappear in reservoirs, in other cases communities relocate leaving no historical footprints of consequence. Nova Ponte on the Araguari River in Minas Gerais, Brazil was uprooted to make room for a dam by the same name [56]. In general, the new town emerged out of negotiations involving the population of the old town. Replacement houses of 46 different designs were available, but the old and new houses were to be comparable in size and quality. A small house was not to be replaced with a larger unit. In the German brown coal districts, community relocation and environmental restoration are carefully implanted and monitored. Hydropower projects and their uses point to the prioritization as perceived and planned by state political decision-making.

The development process pits environmental integrity against society's resource consumption practices. In case that the development process surges ahead, the environment turns vulnerable to development hubris. Hydroelectric dams, their uses, further energy availability and this unleashes tensions of its users who seek more power without the needed disposition how to improve the environment in use (see [57]). Development to be effective has to include the spark of conservation for long-term productivity. How can the idea of conservation inspire those who have nothing to consume?

6. Electricity generation and the environment

Paternity in electricity generation is a model of promiscuity. Gas, nuclear, solar, biomass, coal, water, petroleum, geothermal, eolian, uranium, tidal waves, any and all of the above can be harnessed to generate electricity. Possibly the least attractive aspect of hydroelectricity is its heavy dependence upon reservoir space to regularize electricity

Table 3
The world population of dams: 1998–1999 in %[a]

Region	Water supply	Irrigation	Hydropower	Flood control	Other[b]	Total
Europe	17	19	33	3	28	100
Asia	2	63	7	2	26	100
North & Central America	10	11	11	13	55	100
South America	13	15	24	18	30	100
Africa	20	50	6	1	23	100
Oceania	49	13	20	2	16	100

[a][48, p. 376–81].
[b]This includes multi-purpose and recreational units.

generation. Reservoir size influences significantly duration of water availability and project longevity. It is the reservoir size and water residence that form the parameters of the environmental concerns expressed. Associated with this consideration is the impact upon the water fauna, especially the pisciculture in the changed water body. Reservoir size is related to the productive time that is project associated. The larger the reservoir, the slower the siltation rate [58]. This trade off is notably unpopular with IRN adherents. As observed elsewhere, in the goemorphlogists' perspective, dams are unacceptable. While agreement comes easily with that point of view, reality is relentless; hence optimal conditions further the environment's needs for its best maintenance.

The use of dams worldwide is varied in size and functions. Ackerman [59], Fels [60], Gleick, and the World Commission on Dams [48] provide a general overview. The Table 3 identifies Europe as having the largest percentage of its dams in waterpower in 1999. The "other category" is a dominant group, but irrigation in 1999 accounts for 63% of all dams in Asia, and Africa is in second place with 50%.

7. Hydroelectricity in the real world

Reflections and projections, hope and realization, electricity demand and electricity generation, infrastructure provision–creation, and functional distribution, these variables need to merge into a functional whole to meet changing society's electricity needs. Diversity in resource bases, in infrastructure systems, in domestic economic structures, in variations in living standards, in environmental management, any and all of these invite broadly reasoned understanding, suggestions, and recommendations for individual state electricity policies. As per captia electricity consumption comes closest to a level of similar values, electricity policy recommendations stand to gain in wider applicability in using this data for electricity planning.

Advances in volume of electricity consumption worldwide and rising per unit used energy costs extend to more users, more productive uses of available electricity sources will include hydropower. For some states the hydroelectricity sector could be curbed for a time as replacement energy sources could take the place of hydropower. As demand for electricity continues to rise and non-renewable energy sources shrink, a different energy world and more adaptive energy policies in general will share the current energy stage and ultimately change its composition/configuration.

States that have access to hydropower to meet current needs and a share of future electricity needs can be expected to bring the economically viable proportion into production. Hydropower is a "bridge," not a solution to a state's energy needs. Even if a suitable energy source for electricity generation were to appear this very instant, its implantation to service the world would require 25–30 years, if not more to install. Remember, there are the costs to replace, to build, and there will be losses connected with that part of the infrastructure turned obsolete. The role of hydropower gains in the eco. -pol. spheres and illustrates the flawed agenda to denegrate it [61]. There are two bridges that most of the world's states should be encouraged to use:

1. the hydroelectric one to reduce dependence upon fossil fuels, which are environmentally very unattractive, and finite in availability, and
2. less discussed, but more significant, and least costly among the numerous options. "Conservation" in its diverse forms would curb resource extraction, and contribute significantly to environmental conservation and its protection.

Effective energy uses depend upon systems that transform specific energy-yielding resources into the desired energy kind. Even in a simple setting where wood serves to boil water a few elementary steps have to be taken to achieve the desired outcome, namely boiled water in this case. Hydropower for its part depends upon the effective placement of turbine, rotor and transmission system. Hydropower is a primary energy source, there is no material alteration in the resource to be used, water. The water enters the penstock, gravity and compression do their part, the water gets to the turbine forcing its rotation and thereby activating the rotor which produces the electricity. No resource transformation takes place in this process, the resource transport is mechanically controlled, but without resource alteration; it is water in and water out. The productive operation of a hydropower system is influenced by reservoir size [58] and its management. Large projects readily serve 100 years, but 150–200 years of electricity generation for the larger projects, such as Tucuruí, Itaipu or Niagara Falls are feasible.

As cited above, the browncoal fields in W. Germany illustrate that energy production causes socio-environmental dislocation, more severe, than generally cited in connection with hydropower projects. Browncoal field resettlement proves costly. At Yacyreta, Argentina–Paraguay, resettlement added about 18% to project costs. In the case of Iron Gate Dam, Danube, resettlement cost reached 30% [61, p. 48]. When the costs of environmental impact, resettlement, land acquisition costs, are summed, the ardor to build hydropower cools until the oil equivalent gets traction, and even nuclear has been re-invited to the energy analysis table and that is an intimidating guest (Tables 4 and 5).

The idea to pump more oil, mine more coal, drill for more gas, build more wind farms, install more geothermal plants, plan more hydropower projects, expand the nuclear generating systems, none of these answers the basic challenge. The point beyond which these resources reach their respective supply limits will present itself sooner rather than later.[5] Pressure in the form of high petroleum prices, and by extension the increased price

[5]Reuters reports that Ontario, Canada announced that it will delay the deadline for shutting down all its coal-fired plants. Originally planned for 2007, replacement power sources will not be ready until 2009. About 7500 MW replacement infrastructure will be needed. Energy transition does not come easy. Reuters (2005), "Idling of Canada's Coal-Fired Plants Delayed," The Wall Street Journal, 16 June 2005, A-15.

Table 4
World electricity production—total in 10^9 kWh

	1950	1960	1970	1980	1990	2000	Δ% 1950–2000
World	154, 072	520,755	1,125,392	2,013,066	2,746,127	3,377,828	2093
Asia	14,912	36,631	138,537	324,294	572,942	1,020,013	6700
Africa	3521	9264	24,116	42,898	72,742	101,463	2780
Europe	83,259	171,885	330,832	534,753	678,338	1,055,070	1167
North America	_	215,253	416,711	742,989	926,446	981,638	(1960–2000) 356
Oceania	2989	7680	19,976	32,992	45,750	54,370	1700
South America	5056	13,321	29,070	68,383	116,809	165,274	3200

Source: UN, 1984, p. 630–45 [62]; [21, p. 372–96]; [2, 276–406].

advances in the other energy sectors, is spilling over into the search for additional, but especially one or several energy sources that can meet global energy needs and requirements. In Europe, coal provides about 50% of all electricity used, in the US it is nearly the same at 53%. China and the US consume 55% of the world's annual coal production. For how long can the world sustain this kind of coal dependence? (see Lander [63], "For Europe", The New York Times, 20 June 2006, A-1, C-4; Goodell's Big Coal, 2006 [64]). Moreover, when the transition to the different energy source is at hand, most of these energy sources will turn obsolete. The capital resources spent on their respective expansions would be better and more wisely invested in the energy source(s) that will take the place of what is currently in use. Rather than expand existing energy systems, including hydropower, capital resources need to be channeled into replacement energy source(s). This transition may include a changed electricity demand frame, the product of technological change and improved transmission lines (super conductivity). With the world experiencing the demographic transition at different rates in the various world regions, the electricity demand patterns may come to follow a somewhat comparable process as the changes in population numbers. Here the focus is on hydropower, that in no way should cloud the vision of its understandably 50–100-year horizon. The transition from vacuum tube- to transistor-to microchip is not to be forgotten. The potential reduction of environmental stresses is an invitation to hasten the introduction of the new energy source(s).

Increased production among different energy sources has by varied means been able to serve the rising energy consumption dating to the onset of the industrial revolution, including electricity uses. The 1950–2000 electricity data provide points of reference to the changes that materialized in magnitude and by region Table 4. These data are suggestive for the changes to come, namely as the world's population number approaches seven billion, and as per capita electricity consumption changes from nearly 2500 kWh/p/year in 2000, what will this value be in 2050 when there could be nine billion people in the world? While predictive values are fragile, how will general energy policy planners anticipate and how does hydropower fit into such scenarios? Here intersect numerous variables which vitiate predicted outcomes. Changing birthrates, high urbanization rates worldwide, improved health maintenance—longer life, shifts in economic income, changing standards of life, rising dependence upon and increased consumption of electricity, converge to encumber electricity planning and market projections over the long term—20 years—with an outsized challenge. Electricity systems will acquire footprints that will include the

Table 5
Selected dam data and projected income at 2 cents/kWh at 57% of installed potential

River	Dam name	Year start/ compl.	kW (1000)	Reservoir in ha	kW/ha	Annual income/ ha (in $)	Income at 57% of cap/ha/year	Income for 50 years at 57% capacity
Curua-una	Curua-una	1968/1977	40	8600	4.65	814.68	464.37	199,679,100
Uatama	Balbina	1982/1989	250	234,600	1.07	187.45	106.85	1,253,350,500
Tocantins	Tucurui	1976/1984[a]	8000	243,000	32.90	5764.08	3285.53	39,919,189,500
Iguacu	Salto Osorio	1970/1975	1053	6100	172.60	30,239.52	17236.53	5,257,141,650
Parana	Itaipu	1974/1991	2600	146,000	86.30	15,119.76	8618.42	62,913,298,000
Parana	Yacyreta	1983[b]/–	2700	142,000	19.00	3328.80	1897.42	13,471,682,000
Sao Fransisco	Xingo	1987[c]/–	3000	8500	353.00	61,845.60	35251.99	14,982,095,750
Uruguay	Salto Grande	1974/1979	1890	78,300	24.10	4222.32	2406.72	9,422,308,800
Bio Bio	Pangue	1993/–	450	500	900.00	157,680.00	89,877.60	2,246,940,000
Volta	Akasombo	1962/1964	833	850,000	0.98	171.70	97.87	4,164,150,000
Columbia	Grand Coulee	1932[d]/1986	10,830	32,400	334.30	58,551.84	33,374.55	54,066,150,000
Caroni	Guri	1963/1986	10,500	328,000	32.00	5606.40	3195.65	52,408,660,000
Nile	Aswan	1956/1970	2100	400,000	5.30	928.56	529.28	10,585,600,000
Zambesi	Kariba	1955/1959	1266	510,000	2.50	438.00	249.66	6,366,330,000
Yenisei	Sayanskaya	1980/1989	6400	80,000	80.00	14,016.00	7989.12	31,956,480,000
Zambesi	Cabora Basa	1969/1974	4150	380,000	10.90	1909.68	1088.52	20,681,880,000

Source: [65, p. 227].
[a]First phase is rated 4020 MW.
[b]When completed, 4000 MW.
[c]Projected for 5000 MW.
[d]Not completed.

Table 6
Changes in world electricity consumption 1950–2000 world and its regions

	1950 (kWh/p/year)	2000 (kWh/p/year)	1950–2000 (%Δ)
World	382	2431	536
Asia	41	1291	3049
Africa	66	517	683
Europe	773	5188	571
Oceania	1019	8360	720
North America	2061	9765	374
South America	167	2062	1135

Source: UN (1984) Energy Statistics Yearbook 1982, New York, UN, p. 684–710 [62]; [2, p. 478–494].

international system of electricity generation. In the energy world, for electricity systems it is no longer wise or functional to depend exclusively upon the physical resource base for energy by adding energy sources. Electricity consumption has to be reigned in by higher costs per kWh plus taxes, fostering electricity conservation on one hand; on the other hand, heavy emphasis needs to be placed on significantly improved mechanical electricity technology, as was the case from the vacuum tube to the transistor. It is essential to achieve increased productivity with significantly reduced electricity input!

8. Hydropower as energy bridge and possible additional energy systems

Whether one considers the energy matrix of any state in the world or the global energy matrix, it is a composite of multiple energy sources. These range from biomass to nuclear and photo voltaic systems. Each energy source thus cited is an "additional" not "alternative" energy source. At this time, 2006, the global energy system depends upon an aggregate of energy sources, as there is no one "alternative" energy source to replace the current energy mosaic in use world wide. Each available or additional energy source has the potential to contribute to the enlargement of the general energy pool, but whether it can serve as an "energy alternative" is a very different consideration. And almost always an unlikely condition. While the available options and potential possibilities are numerous, each needs to be assessed and measured for its particular potential and actual contribution. To produce an "alternative energy" source on a global scale is of a magnitude difficult to fathom. In 2006, the global petroleum production is about 82,000,000 (= 11,714,286 m tons/day) barrels per day, the coal production in 2004 was about 12,923,230 m tons/day (or 4,716,978,100 m tons/year). The Chevron Glossary is attached to provide an overview how one petroleum firm identifies its operational context [66] (Appendix A). To replace these two energy sources provides a frame of reference, and suddenly the 20% position of hydropower in the world projects a tangible measure for applying the term "alternative energy." Each "additional energy" source contributes to eventually reach the viable "alternative energy" source. Fusion and fission may be in the wings, but when will either enter service?

Proponents of "alternative" and "additional" energy sources deserve all possible intellectual and material support. Each new idea opens new vistas and creates additional technical options. Any such enterprise can only be assessed when placed in larger systems context and be evaluated for its magnitude of potential energy production. At this time the

US daily petroleum requirements (July 2006) are 20,000,000 barrels per day. Can the US produce 20,000,000 barrels of ethanol per day? How much land is required to produce 20×10^6 bls/day for 365 days? That leaves the question of how much energy is required to produce this amount of corn, process it, and then get it into the distribution system. While this poses a notable challenge, it raises the question of how to structure energy generation investments to achieve energy autarchy. In using ethanol, energy output is enlarged without achieving needed energy autarchy, or an ''additional'' and not an ''alternative'' energy source. If US annual ethanol output were raised to 5×10^9 gallons/year, that would meet at most 1.63% of petroleum needs as of July 2006. This provides a reference marker to the enormous challenge to replace a key energy source and to ''add'' as many ''additional'' energy sources to serve the national need., interests and environment as possible (see Barrionuevo, Romero, Slanofsky ''For good or ill'', The New York Times, 25 June 2006, A-1, A-18 [67]).

Biofuels were featured in *Science* for their respective potential to contribute to the US energy balance. As already noted, a welcome enlargement of the potential energy pool [68,69]. The analytical responses to these ideas point to the challenge and its complexity. Geographically and environmentally it points to much narrower questions than most observers anticipate or consider. In one letter it is noted that 500 kg of grain feeds a person/year, to move a car 20,000 km/year at 7 l/100 km would require 3500 kg of grain, or one car eats for seven persons [70]. The challenge is wise resource use rather than focus on potential energy resources that are wanting in global distribution.[6]

Pressure upon the world's energy system has gained prominence and recognition in large part as a consequence of the steep advance of petroleum prices within the last 4 years (2002–2006). Notable for the US is the absence of a well-structured national energy policy and plan. With the advances in global industrialization, what are the prospects to achieve near universal energy autarchy? Hydropower cannot deliver that status, but it can serve as an important ''energy bridge'' well illustrated in Brazil where two hydropower projects provide nearly 35% of all electricity used in Brazil (Itaipu with 14,000,000 MW, and Tucuruí with 8340 MW).[7] Another way to assess hydropower is what is the return per hectare of reservoir area per year. Economic measures afford comparative analysis. If the

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[6]Biomass as an energy option draws attention and Brazil is using sugarcane-ethanol to achieve energy autarchy in 2006. In the US corn is to serve a comparable end. J. Deutsch notes that 1–2 million barrels of ethanol could be biomass derived in the US, or in 2006 that would be 5–10% of daily petroleum use (Deutsch, 2006). How much energy is required to produce this amount is left for the reader to calculate. This illustrates the challenge and fails to support the Archer Daniels Midland (ADM) slogan ''Resourceful by Nature.''

[7]The expression ''small is beautiful,'' given wide circulation [71], has ready appeal. Small hydro generally finds favorable acceptance, but the acceptors tend to be unfamiliar with its base costs and level of productive dependability. In much of Brazilian Amazonia isolated communities depend upon thermal electricity, rather than hydropower systems. In late 2005 a severe draught caused serious water shortages in the mid-Amazon region for the first time in 45 years. The condition became a very serious supply problem for the isolated populations, notably for food and water. Consider this in context of small hydro or thermal power plants. Politics and planning too often fail and energy systems mirror the political spirit of the moment rather than the long-term necessities. Electrobrás produced an inventory of these isolated Amazonian communities, and in 2005 projected a $\$4 \times 10^9$ petroleum bill to provide timed (timed means a set no. of hours per day) electricity services to the isolated urban places. For the same budget year, Electrobrás was given a $\$4 \times 10^9$ budget to build hydroplants. The source who shared this information was concerned for economic and environmental reasons. Furthermore, if $\$4 \times 10^9$ goes to petroleum, at least 12–15% of the $\$4 \times 10^9$ will go into service and transport cost. Whether all the petroleum reaches its destination is another question. Energy policy and energy politics form an ''odd couple,'' hence national needs and sectorial interests should contribute to maintain an agnostic spirit.

kWh is rated at two cents, and a dam's installed capacity operates at 57% of its potential for the year, Pangue dam, Bio Bio, Chile, generates nearly \$90,000/ha/year, or Grand Coulee, Columbia R., USA, comes in with \$33,000/ha/year, and Tucuruí, Tocantins, Brazil, delivers \$6,000/ha/year for its electricity output (see [65]) (Table 5). Since hydropower projects have a productive period of 100 + years, their role in the national energy systems is far more significant than generally recognized economically or environmentally. Hydropower has a far larger part in the effective coexistence of society and environment than generally considered.

9. Hydropower: technological possibilities and coexistence as norm

In historical perspective humanity gravitated toward social organization. Social organization brought with it the creation of order, which depended upon production and production depends upon work. Much of work is repetitive, requiring energy. This set in motion the search for energy sources replacing human effort, work. From waterwheel to turbine spans several thousand years, and high-energy costs in the 21st century and changing technology are agencies of further transitions in the energy systems. Those states of large hydropower potential will increasingly make use of these options, notably China, Canada, Russia, Brazil and The Congo (see [72]). China has plans to build three dams in the next decade that have the potential of 12,000 MW or larger each. Lemperiere calculates that existing and planned dams will save about 50 Gt of petroleum and an estimated 100 Gt of coal in the 21st century and obviate the need to build 500 nuclear plants whose productive span is 50 years [72, p. 106]. The long life of dams and their low cost operation and management for the 21st century spells operating economies of an estimated \$15 trillion. Lemperiere projects that by 2050 hydroprojects will produce income of \$500 billion/year on a \$150 billion investment/expenditures ([72, pp. 107–8]).

Technology changes conditions, options and opportunities. The Madeira hydro complex above Porto Velho changes the parameters of hydroproject planning. At Porto Velho, Róndonia, Brazil, the river averages 18,000 m^3/s for the year. This forms part of the Amazon lowlands, hence a dam of 50 m height at the Santo Antonio rapids would mean a reservoir extending upstream into Bolivia. The proposed project will be a power house of 44 bulb turbines, and the highest dam will be 15.2 m. These are run-of-the-river units, reducing reservoir size to little more than the flood plain. This opens changed vistas on how to use hydro in large lowland rivers (Arantes Porto et al., 2006, Hydropower, pp. 78–80 [73]). Several decades ago it was suggested to build a dam on the Amazon. While it may be physically possible to accomplish such scheme, from a physical geography perspective it is a "no go, no way" idea.

Bulb technology affords to rethink the use of the Amazon River as a significant source for hydropower. It should be possible to design bulb turbines that could be implanted on pylons in the river, moveable with river level variation to maintain constant pressure on the water flow through the turbine. The turbine may be placed at a certain depth in the river to maintain constant pressure to optimize generating levels. Such turbines could be installed at equidistances, e.g. at 1 km, and their installation would not interfere with river navigation. If 1000 units of 50 MW were installed, 50,000 MW equals 2.5 million barrels of petroleum. In most likelihood, installed capacity and actual electricity generation would be high, and 90% as an estimate may

approximate reality. Similar options may be applicable for the lower Yangtze, the Congo, the Paraná in Argentina, or the Orinoco in Venezuela, as potential sites for such technology. The resource conservation, environmental protection, and resulting economy may serve as incentive for better planned resource management.

The Madeira project illustrates the adaptive property of hydropower as energy source. As the world system grows increasingly energy dependent, it is essential to turn to creative options and curb and reduce the depletion and exhaustion of extant energy resources. The future "alternative energy" exists; it is the technology to harness such source (or sources), which at this point is inadequate or undeveloped. Ocean and solar energy await effective utilization by means of functional technologies. It is essential to link technology, bulk and environmentally clean systems when planning for the "alternative energy". The time required to achieve this goal is conditioned by domestic energy policies, competition among firms producing energy, international politics, stress on energy conservation, environmental protection and not least energy prices. "Study Cites Plan to End US Oil Imports" [74], and this would be in effect by 2030, or at least 24 years hence. Energy projects of any magnitude have predictable time frames; the attention is on energy, but the time element is sensitive, shapes thinking and energy policy decision-making.

Among renewable energy sources, eolian and geothermal sources should be drawn into the energy matrix as much as possible. Both are non-pollutant and accessible in many parts of the globe. Both are established as electricity sources, geothermal energy is a heat sensitive source, hence its exploitation depends upon careful use which will make it a very predictable electricity producer. Hydropower will continue to serve as "energy bridge" and contribute to the economy and environmental protection. Ultimately, while societies embrace higher living standards, there has to be a corresponding thrust in energy conservation and significant improvements in energy use at all technological levels. An example of this distressing imbalance is the automobile. As a means of transportation it is excellent. Merely consider the S.U.V. in terms of energy and space requirements and its impact upon the environment. The impending energy transition may impose changes that may be considered unusual, but the energy needs and problems are no longer local, they are global. Hydropower is well positioned to contribute effectively as "energy bridge" to the impending energy transition. It has become necessary to plan for and anticipate a massive "energy transition". The era of patchwork solutions is best relegated to history. The future of electricity is invention, electricity conservation, and especially environmental protection.

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Appendix A

GLOSSARY OF ENERGY AND FINANCIAL TERMS

ENERGY TERMS

Additives Chemicals to control engine deposits and improve lubricating performance.

Barrels of oil-equivalent (BOE) A unit of measure to quantify crude oil and natural gas amounts using the same basis. Natural gas volumes are converted to barrels on the basis of energy content. See *oil-equivalent gas* and *production*.

Condensate Liquid hydrocarbons produced with natural gas, separated by cooling and other means.

Development Drilling, construction and related activities following discovery that are necessary to begin production and transportation of crude oil and natural gas.

Enhanced recovery Techniques used to increase or prolong production from crude oil and natural gas fields.

Exploration Searching for crude oil and/or natural gas by utilizing geologic and topographical studies, geophysical and seismic surveys, and drilling of wells.

Gas-to-liquids (GTL) A process that converts natural gas into high-quality transportation fuels.

Greenhouse gases Gases that trap heat in the Earth's atmosphere (e.g., carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride).

Integrated energy company A company engaged in all aspects of the energy industry: exploring for and producing crude oil and natural gas *(upstream)*; refining, marketing and transporting crude oil, natural gas and refined products *(downstream)*; manufacturing and distributing petrochemicals *(chemicals)*; and generating power.

Liquefied natural gas (LNG) Natural gas that is liquefied under extremely cold temperatures to facilitate storage or transportation in specially designed vessels.

Liquefied petroleum gas (LPG) Light gases, such as butane and propane, that can be maintained as liquids while under pressure.

Natural gas liquids (NGL) Separated from natural gas, these include ethane, propane, butane and natural gasoline.

Oil-equivalent gas (OEG) The volume of natural gas needed to generate the equivalent amount of heat as a barrel of crude oil. Approximately 6,000 cubic feet of natural gas is equivalent to one barrel of crude oil.

Oil sands Naturally occurring mixture of bitumen (a heavy, viscous form of crude oil), water, sand and clay. Using hydroprocessing technology, bitumen can be refined to yield *synthetic crude oil*.

Petrochemicals Derived from petroleum; used principally for the manufacture of chemicals, plastics and resins, synthetic fibers, detergents, adhesives, and synthetic motor oils.

Production *Total production* refers to all the crude oil and natural gas produced from a property. *Gross production* is the company's share of total production before deducting both royalties paid to landowners and a host government's agreed-upon share of production under a *production-sharing contract*. *Net production* is gross production minus both royalties paid to landowners and a host government's agreed-upon share of production under a *production-sharing contract*. *Oil-equivalent production* is the sum of the barrels of liquids and the oil-equivalent barrels of natural gas produced. See *barrels of oil-equivalent* and *oil-equivalent gas*.

Production-sharing contract A contractual agreement between a company and a host government whereby the company bears all exploration, development and production costs in return for an agreed-upon share of production.

Renewables Energy resources that are not depleted when consumed or converted into other forms of energy (e.g., solar, geothermal, ocean and tide, wind, hydroelectric power, biomass fuels, and hydrogen).

Reserves Crude oil or natural gas contained in underground rock formations called reservoirs. *Proved reserves* are the estimated quantities that geologic and engineering data demonstrate can be produced with reasonable certainty from known reservoirs under existing economic and operating conditions. Estimates change as additional information becomes available. *Oil-equivalent reserves* are the sum of the liquids reserves and the oil-equivalent gas reserves. See *barrels of oil-equivalent* and *oil-equivalent gas*.

The rules of the United States Securities and Exchange Commission (SEC) permit oil and gas companies to disclose in their filings with the SEC only proved reserves. Certain terms, such as "probable" or "possible" reserves, "potentially recoverable" volumes, or "resources," among others, may be used to describe certain oil and gas properties in sections of this document that are not filed with the SEC. We use these other terms, which are not approved for use in SEC filings, because they are commonly used in the industry, are measures considered by management to be important in making capital investment and operating decisions, and provide some indication to our stockholders of the potential ultimate recovery of oil and gas from properties in which we have an interest. In that regard, *potentially recoverable* volumes are those that can be produced using all known primary and enhanced recovery methods.

Synthetic crude oil A marketable and transportable hydrocarbon liquid, resembling crude oil, that is produced by upgrading highly viscous to solid hydrocarbons, such as extra-heavy crude oil or *oil sands*.

FINANCIAL TERMS

Cash flow from operating activities Cash generated from the company's businesses, an indicator of a company's ability to pay dividends and fund capital programs. Excludes cash flows related to the company's financing and investing activities.

Cumulative effect of change in accounting principle The effect on net income in the period of change of a retroactive calculation and application of a new accounting principle.

Goodwill The excess of the purchase price of an acquired entity over the total fair value assigned to assets acquired and liabilities assumed.

Margin The difference between the cost of purchasing, producing and/or marketing a product and its sales price.

Net income The primary earnings measure for a company, as determined under United States Generally Accepted Accounting Principles (GAAP), and detailed on a separate financial statement.

Return on capital employed (ROCE) Ratio calculated by dividing net income (adjusted for after-tax interest expense and minority interest) by the average of total debt, minority interest and stockholders' equity for the year.

Special items Amounts that, because of their nature and significance, are identified separately to help explain the changes in net income and segment income between periods and to help distinguish the underlying trends for the company's core businesses.

Stockholders' equity The owners' share of the company – the difference between total assets and total liabilities.

Total stockholder return (TSR) The return to stockholders as measured by stock price appreciation and reinvested dividends for a period of time.

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Source: [60].

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